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Design operations-and-maintenance-friendly pressure vessels—Part 1

Many scholarly articles have been published on the design, selection and fabrication of pressure vessels.[1–3] The articles, books and training materials published to date focus on the requirements of vessel designers and the manufacturers. None of the published literature appears to address the needs and concerns of the ultimate beneficiaries—the end users.

For vessel designers, fabricators and quality control inspectors, this is a one-time responsibility. They probably never look back once a vessel is out of their territory. The reason is simple: almost all pressure vessels are designed per specific requirements of the asset owners. A few proprietary designs are exceptional cases, such as reactors, desalters and coalescer vessels, etc. However, only the internals would be proprietary, and the base vessel would still be required to comply with the owner's general specifications. In such cases, it is important that the end users do not feel overwhelmed by the proprietary designs and adhere to their company's basic vessel specifications.

Note: This article is the first in a series of design articles intended to increase awareness of operational and maintenance-related concerns and what design engineers can do to provide user-friendly and fit-for-purpose equipment for the hydrocarbon processing industry (HPI). This series is based on the actual implementation of what is narrated and the satisfactory experiences drawn by the end users.

Readers are advised to make their own engineering judgment on the validity of the design improvements suggested herein and to develop their own needs. If engineering or other professional services and judgments are required, then the assistance of a competent professional authority should be sought.

Throughout this article, the terminology "vessel" is used to represent pressure vessels, drums, columns, towers, heat exchanger shells and any equipment designed using pressure vessel codes such as ASME-VIII, EN 13445, PD 5500, etc. The terms "codes, standards, specifications, regulations and recommended practices" are used to broadly define the overall design requirements, recommendations and practices prevailing in the industry. The terms "vessel fabricator" or "manufacturer" have same meaning, as do the terms "owner" and "end user."

Ensuring functional safety and long-term service. Provided here are useful ideas to ensure that a vessel meets functional safety requirements and provides operation-and-maintenance-friendly service to end users over the long term. The tips provided are simple to implement, do not interfere with proprietary designs and do not violate any of the code requirements—rather, they exceed them. The tips are also generic and do not require any code-specific calculations. Therefore, they are applicable to pressure vessels built to any code. This article essentially covers what the codes and design books would not reveal. The tips would lower ownership cost if implemented at design stage and assist the end users to meet their health, safety and environmental regulations, as well as reduce or eliminate field modifications during service life of the vessel. Carrying out field modifications, which invariably requires hot work, is one of the most painstaking exercises in operating plants.

There are many reasons why pressure vessels should be ergonomically designed. Pressure vessels are probably the longest-serving equipment in the HPI. Their life often exceeds the working life of plant personnel, and the vessel can be passed on to the next generation. Even though a facility may cease oil and gas production, a well-maintained vessel would survive. Good pressure vessel design in the initial stages is also important, as there is practically no involvement of vessel designers and fabricators in subsequent field modifications, if any are ever undertaken. For pressure vessels, there are no performance tests to be conducted prior to dispatch. This is true even for proprietary designs. During plant commissioning, vessel manufacturers' representatives are generally not needed—unlike rotating machinery, where the designs are proprietary and machinery manufacturers are usually involved in site performance tests, troubleshooting, modifications works, etc. Many recommendations exist to enhance vessel design.

Design vessels to match outer diameter to piping specs. With the advancement of computer-added design and drafting, the subjective visualization of the actual size of vessels has diminished. Computer printouts are exchanged, and the design is prepared with minimal manual intervention. A typical process software would carry out the inside diameter calculation of a vessel by taking various process parameters into consideration. The software is not programmed to standardize the vessel's outside diameter. The mechanical design software would determine the inside diameter, calculate

pressure wall thickness (including allowances) and pick up the next commercially available plate thickness.

> A vessel must meet functional safety requirements and provide operation-and-maintenance-friendly service. These measures in the design stage are simple to implement, do not interfere with proprietary designs and often exceed code requirements.

The selected plate thickness is added (twice) to the vessel's inner diameter, and the vessel's outer diameter is established and passed on to a vessel fabricator. The thickness formulae in ASME-VIII, Div. 1, section UG-27, "Thickness of shells under internal pressure" is based on vessel inside dimensions. Tubular Exchanger Manufacturers Association (TEMA) standard, section N-1.1 1, defines the nominal diameter as the inside diameter of the exchanger shell.

Supplemented by the American Society of Mechanical Engineers (ASME) and TEMA, and assured by the fabricators that they can build a vessel to match any inside or outside diameter, no effort is made to standardize a vessel's outside diameter. A typical plate bending machine (**FIG. 1A**) can roll a plate into a cylindrical shell with any inner diameter, as long as it is higher than the roller diameter. Plate thickness is the only limitation.

FIG. 1A. A typical plate bending machine.

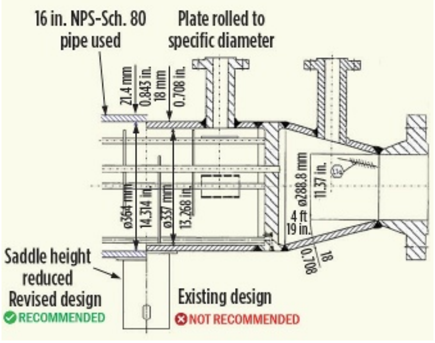

FIG. 1B. Part of an exchanger GA drawing (non-standard shell diameter).

ASME-VIII and TEMA do not encourage standardization of vessels based on the outer diameter. This is in contrast to the piping codes to which a vessel is invariably attached. For example, ASME-B31.3, section 304.1.2 and ASME-B31.1, section 104.1.2 perform calculations based on the outer diameter.

It is recommended that efforts be made to round off the vessel's calculated outer diameter to match with the corresponding pipe outer diameter, e.g., up to 80-in. outer diameter (OD). Beyond 80 in., it may be rounded off in multiples of 6 in. ASME piping standards B36.10 and B36.19 cover pipes up to 80 in. NPS. Seamless pipes are available up to 24 in. Submerged arc-welded pipes (SAW) are available from 16 in. to 48 in. in North America and up to 64 in. in Asia. Use of pipes in lieu of plates is recommended wherever available.

Practical examples. A heat exchanger shell was designed with an inner diameter (ID) of 337 mm, a wall thickness (WT) of 18 mm and an OD = 337 + 18 + 18 = 373 mm (**FIG. 1B**). The fabricator used SA-516, Gr. 60 plates and rolled the exchanger shell. This exchanger failed in service, and replacement exchangers were ordered. Due to NACE compliance, the plates needed to undergo an HIC (hydrogen-induced cracking) test. HIC tests have a 28-day soaking period, and fabrication activities came to a standstill until the results were known.

FIG. 1C. The use of pipes in lieu of plates can save cost and improve integrity. By using single-piece 24-in. and 18-in. NPS pipes, longitudinal and circumferential welds can be avoided.

The problem was referred to the plant engineering team. The fabricated shell was replaced with 16-in. (nominal pipe size) NPS seamless pipe, 21.4-mm WT (Sch. 80). Saddle and nozzle projections were adjusted to ensure no changes to plant piping. Using seamless pipe of appropriate specification avoided HIC test and saved fabrication costs, and units were ready within two weeks. Similarly, another exchanger with an original shell OD of 440 mm, 22-mm thickness was redone using 20-in.-NPS seamless pipe, 508-mm OD and 26-mm WT (Sch. 80). These examples show the importance of engineers reviewing and standardizing the shell dimensions produced by the computers, where possible.

The advantages of vessel OD standardization are:

- Vessel fabricators can acquire seamless and welded pipes for vessel fabrication, wherever available. Short lengths of pipes of approved specifications are usually readily available at fabricators' works and with operating companies. Such pipes with traceable documentation can be approved for fabrication of vessels and exchangers.
- Less time and effort, and lower cost at the vessel manufacturer's shop. Standard templates can be used to verify the OD of rolled plates, and there is no need to fabricate custom-made templates for each ordered vessel.
- Saddle design is standardized, as the outer curvature of vessel is standardized.
- Synchronized pressure/temperature rating of the connected piping and the piping components welded to the vessel, such as nozzle-necks and welding-fittings.
- Extra-long vessels can be fabricated with one piece of pipe. If plates

are used, then a limitation of plate width exists. **FIG. 1C** shows a typical pig launcher barrel fabricated using plates with many longitudinal and circumferential welds.

- If using pipes, a host of time-consuming and expensive quality tests can be avoided. Such tests have already been carried out as part of pipe quality testing procedures.

Use standard materials where possible. In a new grassroots project, it is easy to adhere to exotic specifications, even for small items. The delivery periods for such materials get overlapped by big-ticket items. However, when it comes to maintenance replacements, procurement of items with exotic specifications in small quantities is a bottleneck. In the example given earlier, forged tubesheet to SA-266 was used. Ordering new sheets per SA-266 would take up to four months for delivery. Recovering old tubesheet was not an option as the diameter changed. The tubesheet was replaced with SA-516 plate, which is widely available, easy to fabricate, permitted by the code and posed no quality compromise. SA-516 should have been used in the first instance.

Do not provide side manways on small vessels. Many company specifications require at least one manway on a vessel, regardless of the vessel dimensions. Such manways do not serve the purpose and have many disadvantages:

- Technicians cannot easily get inside
- Fabrication issues: excessive welding heat-input on the self-reinforcing pad tends to distort the vessel
- Extra fittings, such as weldolet and debit arrangement, may be needed
- Projection of manway adds extra dead volume to vessel and may be a surprise to unsuspecting process engineers
- Crevice corrosion in the dead-volume stagnant area, in **FIGS. 2A** and **2B** (left).

One recommendation is for small vessels, perhaps up to 42-in. NPS, to be provided with either a flanged dished-end or a blind flange, depending on the availability. **FIG. 2B** (Option 1 and Option 2) show the suggested configurations. Advantages include:

- Lack of a stagnant dead area, which is unnecessary from a design point of view and detrimental due to the potential for crevice corrosion
- Better liner accuracy for volume control
- Lower costs, as less welding is involved and a davit is not required, as shown in **FIG. 2B**
- Time savings: a fabrication shop would produce dished-end in 24 hr to 48 hr.

In the case of tall and slim columns, as shown in **FIG. 2C,** a split in the middle is very maintenance friendly. **FIG. 2D** shows the original vessel design (simulated image) with a side manway. The change was incorporated during a mechanical review of drawings by the maintenance team.

Bottom nozzles/boot should stay within saddle height. A majority of company specifications require a 6-in. high saddle for smaller vessels and a 12-in. high saddle for large vessels, as measured at the vertical axis of the vessel. This design does not consider the nozzles and boots projecting beyond the saddle. **FIG. 3A** shows such a vessel. It is an unnecessary cost-saving exercise and creates subsequent problems onsite.

FIG. 2A. Manway provided on a small-diameter vessel.

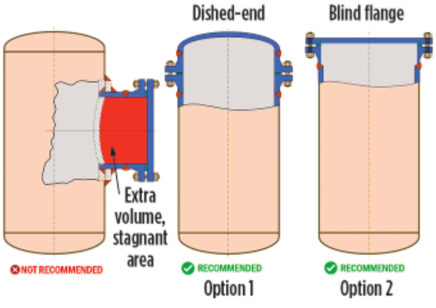

FIG. 2B. Various options for manways on small vessels.

It is recommended to ensure saddle projection exceeds the bottom nozzles and boot projection.

The advantages/disadvantage of tall steel saddles (**FIG. 3B**) are:

FIG. 2C. Manway on the top of a small-diameter vertical vessel.

FIG. 2D. Original design of the vessel manway on the side (simulated image).

- Ease of transportation: In the upstream industry, a majority of vessels are generic gas and oil separators and free-water knockout drums. Vessels are moved from one field to another to meet fluctuating production patterns. In such scenarios, vessels with tall saddles are easy to transport and do not require wooden pallets, in case nozzles and boots project beyond the saddles.
- If the saddle projection is short, it must be compensated with an increased civil foundation height. While this may look like a better option from a cost perspective, it has disadvantages. The piping stresses are transferred to the ground via a concrete pedestal. Concrete is not appropriate for handling piping stresses, as cracks that are difficult to repair can appear. Steel saddles distribute loads much more effectively than concrete. Field preference is for steel saddles that overlap all bottom appurtenances by at least 6 in. (150 mm).
- The only disadvantage for tall steel saddles is that fireproofing costs are marginally higher and may require fireproofing per relevant specification. Tall concrete pedestals would not require fireproofing, as concrete is treated as inherently fire-resistant.

FIG. 3A. Vessel with a short saddle.

FIG. 3B. Vessel with a tall saddle.

Avoid inside projection on manways.

Vessels are usually designed for full vacuum or half vacuum for steam-out conditions. Under certain conditions of full vacuum, the design may dictate the manway to be strengthened in addition to an external reinforcing pad. The most popular method to provide the required extra strength is to project the neck inside and weld circumferentially, as shown in **FIG. 4** (left). This design makes exiting the vessel a very unpleasant, if not impossible, exercise. Another disadvantage of inside projection is that it does not allow complete vessel drainage. The small hole in the projected nozzle does not help effective drainage. An inside reinforcing pad could be a solution, but it would not drain the vessel completely.

Inside projection can be easily avoided by slightly reducing the vacuum required for steam-out conditions, thereby eliminating the projection. The vessel design engineer must adjust the vacuum numbers and communicate back to the process engineer for endorsement. A vessel need not be designed for full vacuum, as it will theoretically not achieve it.

In one case, the vessel design software dictated inside projection due to full vacuum design. The vessel was designed for a high-altitude location where atmospheric pressure was 93.3 kPa. The design engineer used the default software value for an atmospheric pressure of 101.325 kPa. When reduced to 93.3 kPa, the inside projection vanished. It is imperative that the software default values are not used without knowing their implications. What might appear as mundane data at the vessel design stage may be the root cause of an unpleasant experience for operation and maintenance personnel.

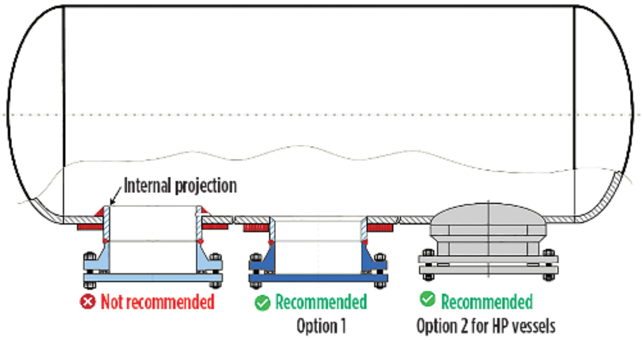

FIG. 4. Avoid inside projection on manways.

Spare nozzles.

Fitting new nozzles on an existing vessel is an expensive proposition. It is worth adding a spare nozzle that can be used at a later date. The most useful spare nozzle is at the top of the vessel, preferably of the same size as the main inlet nozzle.

Cost implications.

The initial vessel cost should not be evaluated in terms of CAPEX alone. If maintenance costs and possible field modifications (OPEX) are combined, all suggested measures eventually reduce the ownership cost of the vessel. Traditionally, the OPEX for static equipment like pressure vessels has been considered to be very low, as compared to CAPEX. That is not true for poorly designed vessels. Producing the correct products in the first instance is a win-win situation for all. HP

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Design operations-and-maintenance-friendly pressure vessels—Part 2

In Part 1 of this article, the assistance provided by standardizations to gain improved vessel performance—vessel outer diameter (OD), component metallurgies, manways and saddles—was discussed. This work will explore other features that can supplement vessel design and improve operations and profitability.

Note: Readers are advised to make their own engineering judgments on the validity of the design improvements suggested here, and to develop their own conclusions.

Throughout this article, the terminology "vessel" is used to represent pressure vessels, drums, columns, towers, heat exchanger shells and any equipment designed using pressure vessel codes, such as ASME-VIII, EN 13445, PD 5500, etc. The terms "codes, standards, specifications, regulations and recommended practices" are used to broadly define the overall prevailing industry design requirements, recommendations and practices.

Avoid fireproofing and flanged joints inside the skirt.

Many company specifications ask for fireproofing inside the vessel skirt due to the presence of flanged joints. These features create problems for field maintenance. Corrosion under insulation (CUI) and corrosion under fireproofing (CUF) have assumed greater importance and have been known to cause equipment collapses. API's first publication in 2014, API-RP-583, "Corrosion under insulation and fireproofing," underscores the importance of tackling this problem (FIGS. 1A and 1B).

Table 2 of API-583, "Locations for corrosion under insulation and fireproofing," clearly identifies the insulated zone at the skirt weld and fireproofed skirts as areas to be watched for accelerated corrosion and leaks. API Standard 2510, "Design and construction of LPG installations: Section 10.8.4," states, "When a vertical vessel is supported by a skirt, the exterior of the skirt shall be fireproofed." This implies that even for highly flammable services like liquefied petroleum gas (LPG), the interior of the skirt need not be fireproofed.

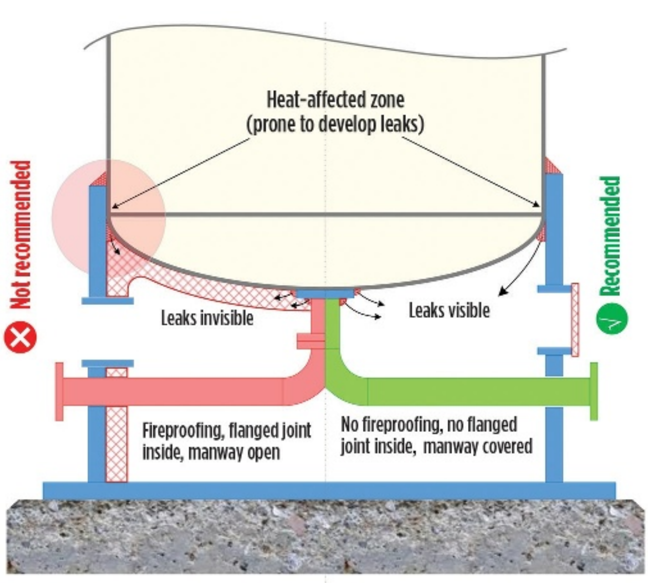

FIG. 1A. Avoid a flanged joint and fireproofing inside a vessel skirt.

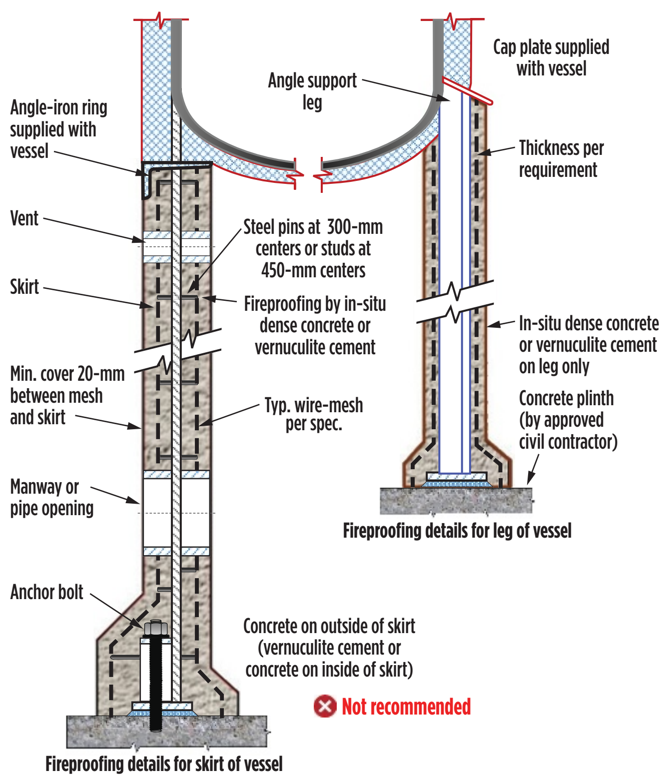

FIG. 1B. A typical drawing asking for fireproofing inside a vessel skirt.

It is recommended to cover large skirt openings with a vented removable cover, preventing plant site waste materials from accumulating inside. Typical site waste materials include plastic bags, pieces of fireproofing/insulation pads, pieces of gaskets, etc. Stray animals have been known to occupy unattended vessels with large skirt openings. The practice of storing small tools and consumables inside vessel skirts should be discouraged from a safety perspective—keeping skirt openings closed is the best option.

Code supports covering skirt openings. API 2510A, Section 5.8.2.2, "Fire protection considerations for the design and operation of LPG storage facilities," states, "The interior should be fireproofed if there is more than one access opening in the skirt that is not covered with a plate." The section implies that fireproofing is not required if skirt openings are minimal and covered. The code indirectly infers that if there is only one opening, it may be left open. However, this should be discouraged. Skirts should always be gas-tested before manual entry.

Adequate sizing of vessel's process nozzle at bottom. Always ensure that the bottom process nozzle is large enough. The recommended minimum is 4-in. nominal pipe size (NPS), regardless of what a computer program dictates. Small nozzles eventually clog, particularly in the upstream industry, even if the fluid is classified as "clean" on data sheets. **FIG. 2** shows a typical vessel where the bottom nozzle was enlarged to 4-in. NPS as a last-minute change. The rest of the piping was left as 2-in. NPS, to be replaced later. Any hot work to a vessel is a herculean task and very difficult for operating plants, but piping changes are comparatively easy and can be accomplished in a routine plant shutdown.

Some engineers prefer a flanged joint inside the skirt due to a reasonable concern that the replacement of an elbow (subject to corrosion and high-velocity erosion) would prove to be a more difficult task. However, experience with large nozzles and elbows with reduced velocity has proved to be satisfactory.

Adequately sized gravity drain nozzle. All vessels that undergo maintenance must be hydrotested and completely drained of water. The potential drainage time for large vessels is an issue in delaying plant startups. Some large vessels take 24 hr–48 hr for a gravity drain. Most company specifications/data sheets do not specify a maximum drainage time under gravity flow. It is recommended to restrict drainage time to 3 hr–4 hr. This information is rarely found on vessel drawings or data sheets, and it is vital for planning of other maintenance activities in tandem.

Literature is available to estimate drainage time under gravity for horizontal and vertical vessels and spheres, and to account for pressure loss in drain piping.[1,2]

FIG. 2. The drain nozzle was enlarged to 4-in. (100-mm) NPS, the recommended minimum regardless of what a computer program dictates.

Reinforcement plate for 150# flanged opening. Code calculations do not dictate reinforcement pads for small-diameter openings, particularly for low-design pressure vessels. Reinforcing pads may not be needed for small-diameter openings, even in high-pressure vessels. A practical example of a water-seal drum is illustrated in **FIG. 3A.** The bottom drain nozzle is 6-in. (150-mm) NPS and welded directly to the vessel without a reinforcing pad, as dictated by the code calculation. Water and a hydrocarbon mixture accumulated inside a skirt, as shown in **FIG. 3A,** and a leak path shown in **FIG. 3C.** As the skirt opening was covered, no dirt was accumulated, reducing the fire hazard and enabling easy cleaning.

Such vessels are difficult to repair when leaks develop through the nozzle weld. As there is usually no available time to make the vessel gas-free and carry out the time-consuming hot work, some technicians use proprietary cementitious materials for sealing the leaks, as shown in **FIG. 3B.** This shortcut is not recommended.

It is recommended to provide reinforcement pads for bottom nozzles, thereby superseding code calculations (**FIGS. 3C** and **3D**). Advantages include:

1. Reinforcement pad provides secondary protection from leaks
2. Leaks can be detected at early stages from "tell-tale" hole
3. Hot work can be carried out from the outside using low-heat electrodes, without the need to make the vessel gas-free
4. If leakage is a persistent problem, a pressure gauge can be installed for early warning, as shown in **FIG. 3E.**

Vessel relief valve fitted with demister pads. Relief valves on columns and towers were previously installed downstream of demister pads. Accidents have been reported where, due to process upsets, the demister pad disintegrated and choked the relief valve inlet. Now, codes require that relief valves remain in an unobstructed path (**FIG. 4**), which means upstream of the demister pads, if any. This recommendation has been subsequently clarified under the ASME-VIII chapter, "Best practices for the installation of pressure relief devices."

Although this recommendation is not retro-effective, it should be possible to modify non-complying vessels by relocating relief valves on the side inspection openings available on most vertical vessels. If installed upstream, the relief valve size must be reconfirmed due to possible liquid carryover to the relief valve. If valves are installed sideways and discharge in the open, then care should be taken to strengthen the side nozzle per API-520, Part 2, Section 4.4.1. Recalculating noise at grade per API 521, Section 5.8.10.3 is appropriate due to the slightly higher noise level at grade caused by the lower elevation of the relief valve. A vessel nozzle that is one size larger than the relief valve nozzle is preferred for possible future upsizing of the relief valve. Using a reducing elbow is

preferred from a stress and lower pressure-drop point of view, as compared to a standard elbow and a reducer combination.

Avoid internal ladder in corrosive service. Internal ladders installed in vertical vessels in corrosive service and in vessels packed with internals serve little purpose. Such ladder rungs create safety hazards and obstruct installation of scaffolding for maintenance works. **FIG. 5A** shows lower ladder rungs that have corroded and fallen apart, which could be attributed to a higher concentration of corrosive fluid in the lower stagnant portion of the column.

The integrity of such ladders, including the rungs, is doubtful. Ladder rungs are made from ¾-in. (20-mm) bars and welded to the vessel wall, sometimes with poor workmanship. Due to corrosive media degradation, the welding is insufficient to sustain a human load. The wear plate design is also questionable (**FIG. 5B**). Typical wear plates require ¼-in. (6-mm) tell-tale holes to ensure porosity-free welding. The tell-tale hole provided from a good welding aspect only assists corrosive fluid to enter the cavity and expedites the detachment of the wear plate from the vessel wall. What began as a good intention from the design phase could potentially prove fatal for field personnel.

In this particular case, due to severe corrosion, the ladder rungs were removed and the area ground flushed and painted. An aluminum ladder lowered from the manway proved to be a good temporary substitute.

Nozzle openings through welded seams. It is a general impression that opening through welded seams is not permitted by codes. Such openings are often detected only in the late stages of vessel design, when the plate-cutting diagrams have been prepared. An owner's design engineers are not involved in the review of plate-cutting diagrams, and (at this stage) the vessel general arrangement (GA) and piping GA/isometric drawings are already frozen. To avoid openings on welded joints, nozzles are relocated and related piping is rerouted. This exercise is expensive, time-consuming and unnecessary.

ASME-VIII, Div. 1, UW-14, "Openings in or adjacent to welds," permits this practice, as does ASME-VIII, Div. 2. The overlap of reinforcement pads of adjacent openings is also permitted. **FIG. 6** shows a Div. 2 vessel with a manway located on a circumferential seam weld. The vessel has been in intermittent service for the past 39 years without any leaks.

Proper relief valve nozzle sizing. A vessel relief valve opening one size larger than the relief valve inlet nozzle is recommended (**FIG. 4**). A reducing elbow design in lieu of a standard elbow and reducer is preferred and helps field personnel avoid hot work in case a larger relief valve is needed in the future. Vessels have a long life expectancy among major process equipment, and should manage increased gas flowrates in aging production fields.

Separate as-built drawings for each vessel. Some vessel manufacturers provide only one set of as-built drawings if multiple identical vessels are ordered. For two identical vessels, V-101A and V-101B, these manufacturers will provide only one set of as-built drawings tagged as V-101A/B. The mantra, "All work is completed by computer numerical control (CNC) machines, so all vessels are identical," is a paperwork-saving shortcut approach that does not help the end user. At times, only one vessel may be modified in the field, so one set of as-built drawings for each tagged vessel (V-101A and V-101B) are vital. Third-party inspectors should ensure compliance and insist on signing off on each set separately. This requirement is applicable only for as-built drawings. During design stages, only one set of GAs should be provided tagged as V-101A/B.

Transportation and storage notes. While part of an operating company's technical support team, the author was asked for a particular grade of mineral oil. It was discovered that the oil was requisitioned to apply on the inside surface of a vessel before it was put back into opera-

FIG. 3A. Bottom drain connection without a reinforcement pad, which may not be needed for small-diameter openings, even in high-pressure vessels.

FIG. 3B. Leak repaired using cementitious material, a shortcut that is taken when there is no time available to make the vessel gas-free or carry out the time-consuming hot work.

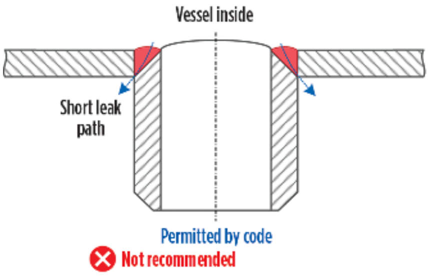

FIG. 3C. Not recommended.

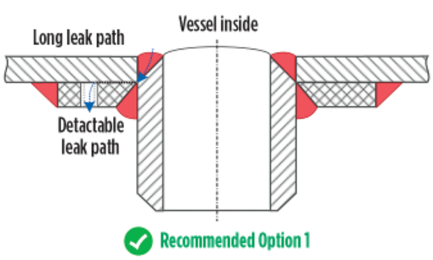

FIG. 3D. Recommended #1.

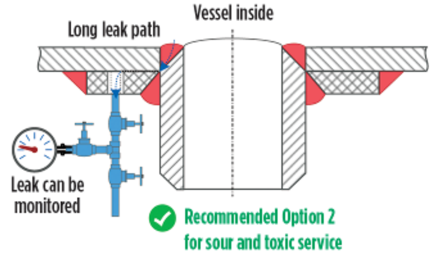

FIG. 3E. Recommended #2 for sour and toxic service.

tion. Further questioning revealed that the vessel GA drawing included the comment, "Mineral oil, grade xxxx, is to be applied inside the vessel." The mineral oil coating was meant for new vessels as a rust preventive during transportation and prolonged storage. The technicians had unknowingly been following the procedure for vessel maintenance.

The lesson is that transportation notes should not be appended on vessel GA drawings. If appended, the purpose of such notes should be clearly stated to avoid confusion, keeping in mind that maintenance personnel faithfully adhere to all instructions stated on vessel GA drawings. The impression that the role of vessel GA drawings ends once a vessel is commissioned is incorrect. GA drawings are a valuable maintenance aid and necessary throughout the life of a vessel. Providing a set of A-3-size GA drawings and internals, no matter how congested the reduced-size copies look, is suggested. Jumbo-size drawings (A-0, A-1) are difficult to handle in the field; photocopiers are rarely available to make copies of A-0 and A-1, and such drawings usually end up in untraceable custody, albeit with good intentions.

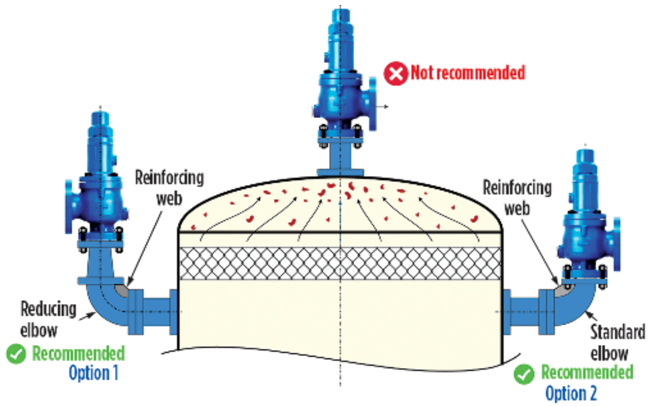

FIG. 4. Codes require that relief valves remain in an unobstructed path. This rule has been subsequently clarified under ASME-VIII.

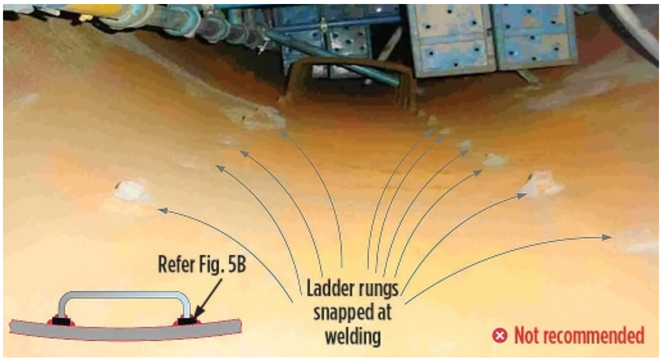

FIG. 5A. Vertical vessel with corroded internal ladder rungs.

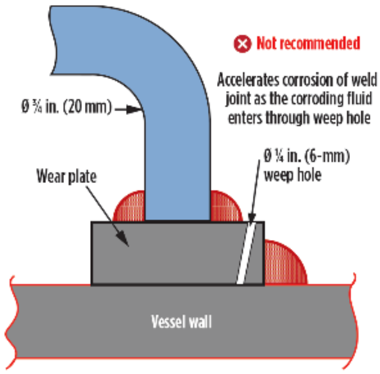

FIG. 5B. Ladder installation details.

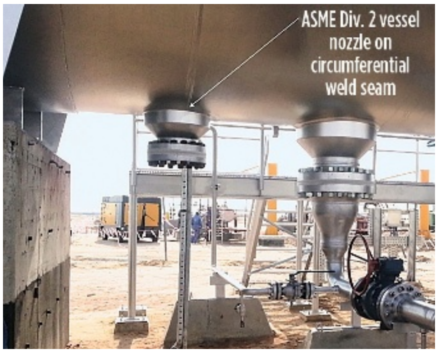

FIG. 6. Nozzle opening through circumferential weld seam.

State vessel operating weight. General protocol dictates that vessel GA drawings provide a vessel empty weight and a hydrotest weight simulating a vessel that is full of water. The transporter must know the empty weight. The hydrotest weight is required by the vessel manufacturer to ensure that the shop floor can handle the load, and it is also used to design the vessel foundation onsite. This works well if the fluid is water or lighter than water.

What happens if the vessel is designed for fluids heavier than water—e.g., sulfuric acid (specific gravity = 1.84)? The fluid weight would almost double, but the GA drawing may still state the hydrotest weight. Cases have been reported where the hydrotest weight from a GA drawing was inadvertently used to design a civil foundation for sulfuric acid vessels, resulting in undue foundation settlements. Specifying a vessel weight as full of liquid for heavier fluids, in addition to usual empty steel weight and hydrotest weight, would be a good practice.

Recertification after repairs. Old vessels sometimes require new nozzles when moved and pressed into another service (**FIG. 6**). New nozzles were added to this 155-t separator vessel. Built in 1977 to ASME Div. 2 standard, the vessel did not have readily available design calculations nor National Board (NB) registration. Nevertheless, the additional nozzles were added and the vessel recertified to Div. 2. The recertification process is not discussed here. The intent is to inform the vessel owners that it is possible to regularize the redundant fit-for-service vessels and recreate the vessel "birth certificate," or "U" certificate. This defies a prevailing notion that an ASME "R" certification cannot be accorded unless an ASME "U" is produced. A redundant fit-for-service vessel need not be discarded for want of repair modifications and missing documentation.

Multiple certification. While oil and gas wells may go dry, a pressure vessel can survive and move to another location. This movement (e.g., state to state) may require different pressure vessel regulations. For this reason, some owners request multiple certifications, which should not pose problems if handled at the design stage. Challenges arise if a vessel is certified for only one state and must subsequently be recertified for use in another. It is advised that design engineers ask vessel end users whether multiple certifications are needed. In this instance, it is better to pay a little extra at the design stage and save undue paperwork, delays and associated expenses later.

The remaining strength of corroded vessels. Despite the existence of ASME B31G, "Manual for determining the remaining strength of corroded pipelines," since early 1980, there was no such docu-

ment for pressure vessels. The author's query to ASME in the 1990s received the following response: "The committee has no plans to develop code criteria providing guidelines for calculating the remaining strength of corroded vessels originally fabricated to the ASME code." In the absence of guidelines, there was a disconcerting practice to treat a vessel as a large-diameter pipe and apply ASME 31G to calculate the remaining strength of corroded vessels. This approach was erroneous and should not have been used.

Realizing the growing demand for the fitness evaluation of aging vessels, API came out with RP 579, "Recommended practice for fitness-for-service," in 2000. Not wanting to be left behind this time, ASME joined in collaboration, and a massive (1,128-page) second edition was published in 2007 as API 579-1/ASME FFS-1. The edition's status was elevated to a "Standard" from the earlier "Recommended Practice." To illustrate the complex calculations used in the assessment procedures of 579-1/FFS-1, API issued an example manual, 579-2/FFS-2, titled, "Fitness-for-service example problem manual," in 2009, a very informative 374-page document. It is recommended that practicing engineers consistently reference the example manual to avoid potential errors and conclude the fitness evaluation of corroded vessels with a high degree of accuracy and confidence.

Summary of cost implications. While a majority of items will reduce vessel ownership costs, some items may slightly increase the initial cost (e.g., reinforcing pads and larger size nozzles for relief valves and vessel bottom outlets).

However, project costs (CAPEX) should not be evaluated alone. If the costs incurred by the plant maintenance personnel in maintenance and possible field modifications (OPEX) are added, then all of the suggested measures eventually reduce the ownership cost of the vessel. Traditionally, the OPEX for static equipment, such as a pressure vessel, has been considered to be very low as compared to CAPEX. This is not true. An undersized gravity drain alone can repeatedly make OPEX much higher than CAPEX by way of lost production year after year.

End of series. Part 1 of this article appeared in August. HP

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